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14. ABSTRACT
Using a nonlinear pump-probe technique, investigations of the carrier dynamics and band structure in MIR Sb-based lasers has been conducted. Specific attention has been given to Type-II QW interband transitions. In addition, measurements of the significant carrier/lattice heating at high temperatures related to slow (~100 ms) thermal diffusion times are reported. Finally, the luminescence lifetime has been found to decrease significantly with temperature showing increased carrier/lattice heating and non-radiative recombination rates.

15. SUBJECT TERMS
Pump-probe techniques, InSb, quantum well structures

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Intervalence band absorption and carrier heating in type-II Sb-based lasers

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Outline

- Laser sample/ Setup
- Sum Frequency nonlinear Pu/Pr technique
- Detection of built-in electric field in type-II QWs
- Resolving the intervalence absorption
- Excess carrier/lattice heating
- Summary

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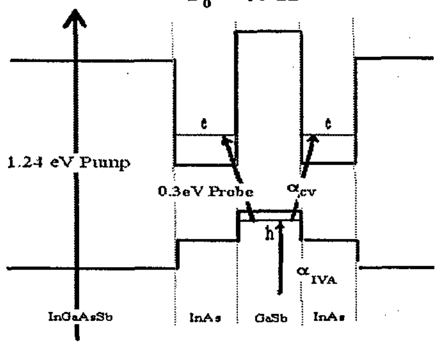
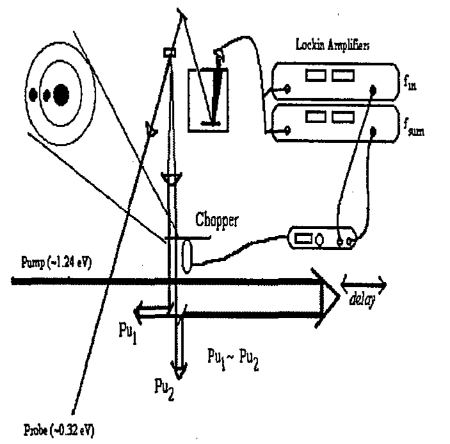
Sample

$T_o = 40$ K



$$\Delta T(N,\varepsilon) = \alpha_{cv}(N)\,[f_e(N,\varepsilon) + f_h(N,\varepsilon)]*C(\varepsilon) - \alpha_{IVA}(\varepsilon) f_h(N,\varepsilon)$$

Setup



Split Pump pulse into two, modulate at f_1 and f_2 detect probe transmission at the sum frequency f_1+f_2

Discuss the sample structure and characteristics. Highlight interband and intervalance contributions. Discuss the experimental setup and technique

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Sum Frequency Pu/Pr

For a thermal distribution:

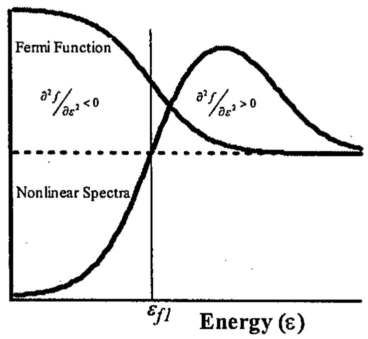
$$\Delta T(\varepsilon,t) \propto f(\varepsilon,N,T) = [1+\exp(\frac{\varepsilon-\varepsilon_f(N,T(t))}{KT(t)})]^{-1}$$

$$\Delta T_{SumFreq} \propto \Delta T(\varepsilon,t)|_N - 2*\Delta T(\varepsilon,t)|_{N/2}$$

$$N = \int_0^{\infty} \frac{\rho(\varepsilon)}{1+\exp[\frac{\varepsilon-\varepsilon_f(N,T)}{KT}]} d\varepsilon$$

$$\downarrow$$

$$\varepsilon_f(N,T)$$



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Highlight what generic pump-probe measure and what nonlinear pump-probe measure

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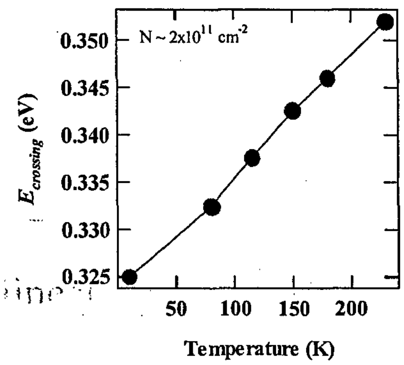
Nonlinear Spectra Crossing Energy

$$f(\varepsilon_{cr}, N, T) - 2f(\varepsilon_{cr}, N/2, T) = 0$$

$$E_{cr} = E_{f1} + KT * Ln\left(\frac{1}{1 - 2\exp[-(E_{f2} - E_{f1})/KT]}\right)$$



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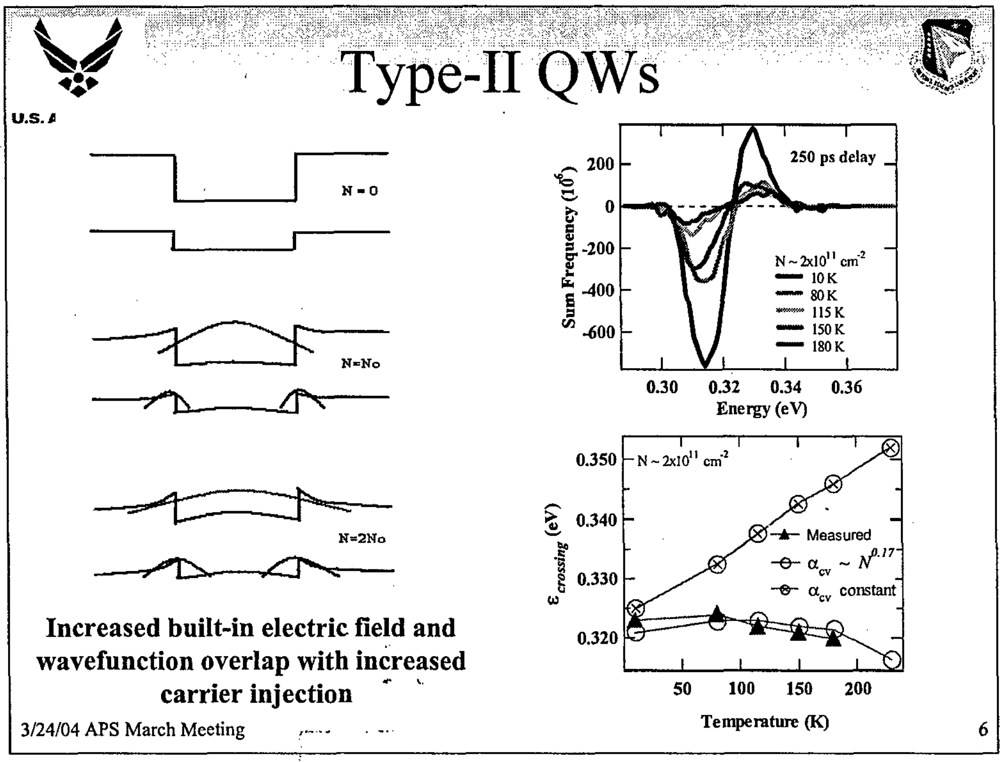
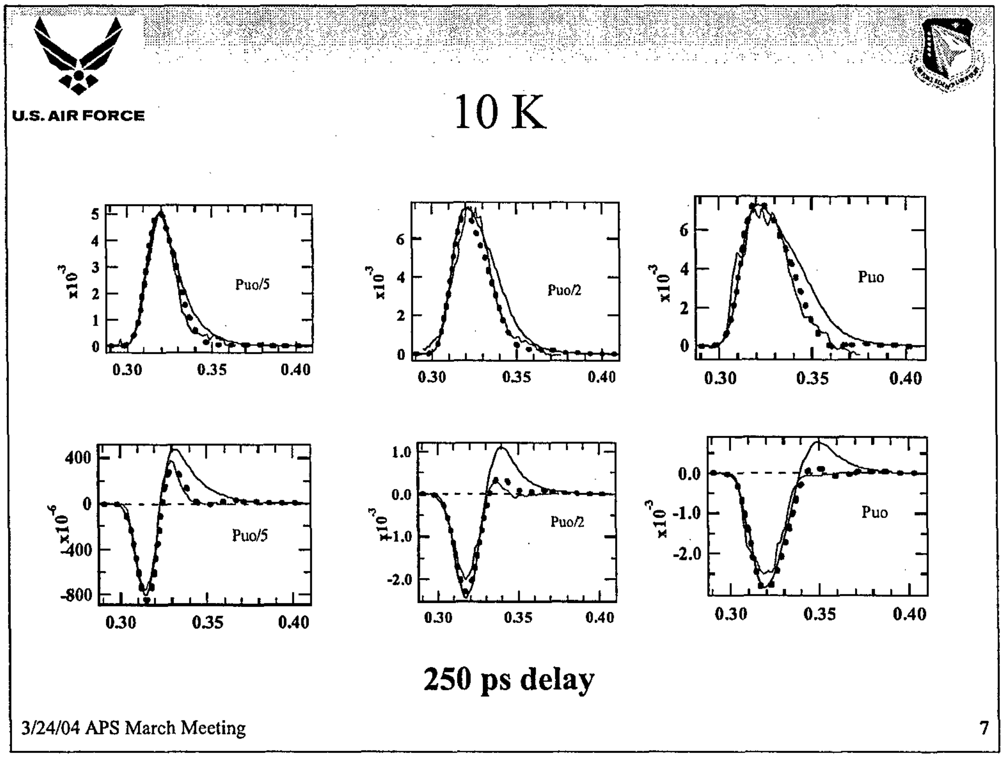
Calculate and plot the nonlinear spectra crossing energy for a constant transition matrix element (type-I QWs)



Discuss the increase of the built-in electric field and wavefunction overlap with increased carrier injection in type-II QWs.

Discuss the measured nonlinear spectra as a function of temperature and simulated transition matrix element that varies as $N^{0.17}$



Discuss the measured linear and nonlinear spectra for different carrier injection densities at 10 K, 250 ps delay.

Highlight the curve fitting taking into account the interband transition only (black line) and the fitting curves with the interband and intervalence transitions taken into account (dotted blue)

Fitting parameters

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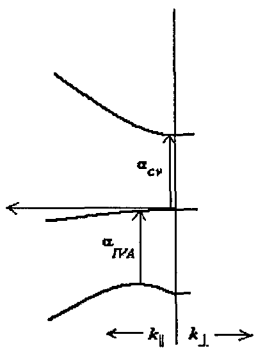
$$\alpha_{IVA}\exp(-[\frac{E-E_{IVA}}{\Delta_{IVA}}]^2)*[1+\exp(\frac{E_{fh}-E_o}{KT})]^{-1}$$



$\alpha_{cv} \sim 2000\ cm^{-1}$, $\alpha_{IVA} \sim 22000\ cm^{-1}$

$E_{IVA} \sim 0.345$ eV , $\Delta_{IVA} \sim 0.013$ eV

$E_o \sim -15$ meV ($k_{\|} \sim 0.02$ Å^{-1}),

$$N(Pu) \propto \frac{Pu}{1+Pu/(1.6Pu_o)}$$

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Discuss the formula used to fit the intervalence absorption, the fitting parameters and a schematic of the energy diagram.

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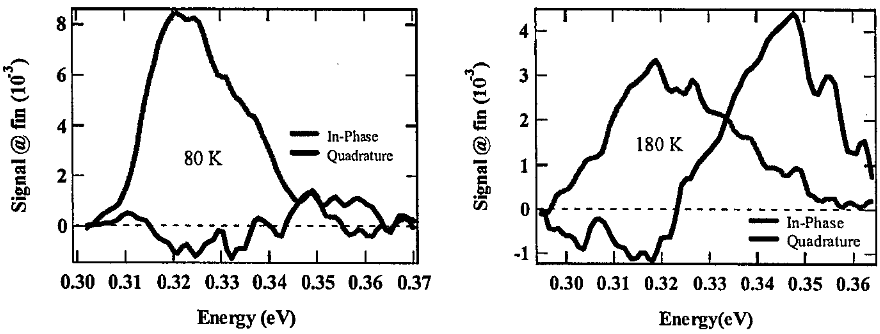
Quadrature Signal

(3 kHz chopping, 250 ps delay)



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Report the observed growth of a quadrature (out of phase) signal at higher temperature.

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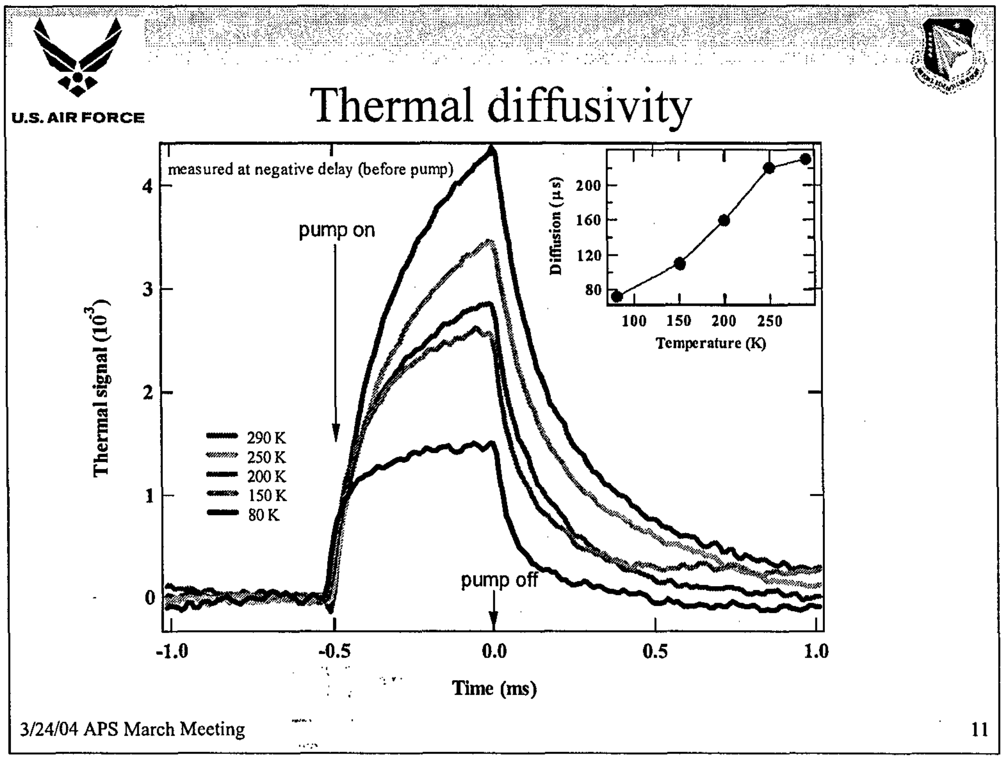
Thermal Diffusion

D_{th} [cm^2 s^{-1}] = K_{th} [W cm^{-1} K^{-1}]/(ρ [gm cm^{-3}] * Cp [J gm^{-1} K^{-1}])

Radial diffusion; $\tau_{th} = A / D_{th}$ (~ 100 μs)



Report the time dependence of the measured thermal signal as a function of lattice temperature for negative delay.

Highlight the dependence of the thermal diffusion time constant as a function of temperature.

Comment about the radial vs. axial thermal diffusion.

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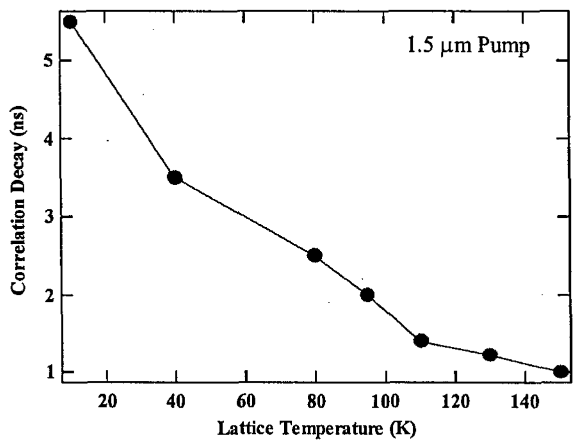
Luminescence Correlation



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Report on the carrier recombination time as a function of temperature measured through luminescence correlation decay.

Correlate with the increased excess carrier/lattice heating and the resonant effect of the intervalence transition on Auger recombination rates

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Summary

- Used nonlinear pump-probe technique to investigate carrier dynamics and band structure in MIR Sb-based lasers.
- Type-II QW interband transition matrix element $\propto N^{0.17}$
- IVA absorption is not resonant with the lasing energy ($k_{||} \sim 0.02$ Å^{-1}).
- Measured significant carrier/lattice heating at high temperatures related to slow (~100 μs) thermal diffusion times.
- Luminescence lifetime decreases strongly with temperature.
- Increased carrier/lattice heating and non-radiative recombination rates points to increased IVA resonance at higher lattice temperatures and higher carrier excitation.